The Interactions Between the Mobile Handset Antenna of Various Types and the Human Head

Adel Z. El Dein[1], Mohamed A. A. Wahab[2], Mohamed M. Hamada[2], T. H. Emmary[1]

[1]Electric Engineering Department, Faculty of Energy Engineering, Aswan University

[2]Electric Engineering Department, Faculty of Engineering, Minia University

[*1]azeinm2001@hotmail.com

Abstract

One lingering concern is the effect of the radiation produced by the mobile handset antenna on the human head. This topic has been studied widely, but still there is no definitive answer. Since mobile telephones are typically used in close to the human head, significant levels of power can be absorbed by the head, the primary effect is to cause local heating of the brain and head tissues. This is of concern to some people who work continually with mobile telephones, and some form of "preventative" research should be done.

This paper describes some kinds of models of antennas (dipole, monopole and patch antennas) and human, and the calculation of the Specific Absorption Rate (*SAR*) in the human head at 1800 MHz. Also, this paper studies the effect of the human head model on the return losses of these models of the antennas.

The obtained results show that at the same frequency, the patch antenna induces *SAR* in the human head of smaller values than that induced by dipole and monopole antennas. In addition, the return loss of the patch antenna is affected greatly by the presence of the human model, when it is compared with the return losses of the dipole and monopole antennas.

Keywords

Antenna Types; SAR; Return Loss; Human Head

Introduction

There are some basic parameters that affect an antenna's performance. The designer must consider these design parameters and should be able to adjust, as needed, during the design process; the frequency band of operation, polarization, input impedance, radiation patterns, gain, return loss and efficiency. The designer should evaluate and measure all of these parameters using various means (*R. Garg, et al., 2001*).

One important parameter, which can be derived from the voltage reflection coefficient Γ, is the Return Loss *S11*. The return loss *S11* is defined as the return loss from the transmitter and back.

$$S11 = 20\log|\Gamma| \qquad -\infty \le S11 \le 0 \tag{1}$$

The *S11* parameter displays the amount of power reflected at a specific frequency.

The voltage reflection coefficient Γ is defined as the ratio of the complex amplitudes of the reflected and incident voltage waves at the load. For passive components the reflection coefficient satisfies $\Gamma \le 1$ can be calculated as:

$$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} \tag{2}$$

Where; Z_L is the load impedance, and Z_o is the characteristic impedance.

This paper aims to compare the induced value of SAR in the human head as well as the return loss with and without the presence of the human head, of three types of antennas (dipole, monopole and patch antennas).

Antenna for Cellular Phones

The most common types of cellular phone antennas used today are retractable (telescope), helical and internal (patch) antennas, and also there are dipole antennas and monopole antennas. But this paper concerns the dipole antenna, monopole antenna and patch antenna.

The dipole antenna or dipole aerial is one of the most important and commonly used types of radio frequency (RF) antenna. It is widely used on its own, and it is also incorporated into many other RF antenna designs where it forms the radiating or driven element for the antenna.

A dipole antenna has an easy structure and consists normally of just a metal wire with a specified length depending on the wavelength. A dipole antenna is easy to produce and therefore cheap compared to other antennas.

Currents from the feed point move along the metallic surface of the wire and introduce an outgoing electric field from the wire. The polarization of the radiated field is linear and parallel to the antenna axis. The antenna can be made smaller with surrounding plastic to increase the dielectric constant (*D. Thiel and S. Smith, 2001*). In practical design, a dipole is usually designed as a half-wave length long element. Usually the dipole is always slightly shorter than a half-wavelength. This is because the capacitive effects of the end insulators and practical conductors which are not infinitely thin, all have finite diameters. The thicker the wire or tube, the shorter the antenna gets. So, the physical length is shortened about five-percent (*W. J. Buchanan, N.K. Gupta, 1995*).

In many circumstances it is more convenient to use a monopole antenna than a dipole. The monopole antenna is essentially a quarter-wave element driven against a ground plane. A monopole antenna is a class of radio antenna consisting of a straight rod-shaped conductor, usually mounted perpendicularly over some type of conductive surface, called a ground plane. The driving signal from the transmitter is applied, or for receiving antennas the output voltage is taken, between the lower end of the monopole and the ground plane. One side of the antenna feed line is attached to the lower end of the monopole, and the other side is attached to the ground plane. Common types of monopole antenna are the whip, rubber ducky, helical, random wire, mast radiator, and ground plane antennas (*D. Thiel and S. smith, 2001*). A monopole antenna can be visualized as being formed by replacing one half of a dipole antenna with a ground plane at right-angles to the remaining half. If the ground plane is large enough, the radio waves reflected from the ground plane will seem to come from an image antenna forming the missing half of the dipole, which adds to the direct radiation to form a dipole radiation pattern. Because it radiates only into the space above the ground plane, or half the space of a dipole antenna, a monopole antenna will have a gain of twice (3 dBi over) the gain of a similar dipole antenna, and a radiation resistance half that of a dipole.

Patch antennas have been used for many years since they have a lot of advantages such as low-cost, conformability and easy manufacturing, though they also have disadvantages such as narrow bandwidth and low power capacity. Patch antennas in cellular terminals are internal antennas. The patch antenna is a thin metal sheet etched on a dielectric carrier structure. The metal patch plane is parallel to the ground plane. In cellular terminals the whole terminal is used as ground plane. Commonly used shapes of a patch are circular, or rectangular, however, it can have a very irregular shape and also have holes in it. The rectangular patch antenna is selected to be designed in this paper. The antenna is usually linearly polarized and the field lines are parallel to the long axis, but the antenna can be also be made with circular polarization. Recently, some approaches have been developed for the bandwidth enhancement (*Adel Z. El Dein et. al., 2010*). One way to enlarge it is to increase the height of the dielectric and decrease the dielectric constant. However, the latter will make the matching circuit more difficult since line width will be wider (*Paul D, Pothercary and Railtion, 1994*). The common structures that used to feed patch antenna are coaxial probe feed, microstrip line feeds, and aperture coupled feeds. The coaxial-fed structure is often used because of ease of matching its characteristic impedance to that of the antenna; and as well as the parasitic radiation from the feed network, which tends to be insignificant compared to probe feeds. Microstrip line-fed structures are more suitable due to ease of fabrication and lower costs, but serious drawback of this feed structure is the strong parasitic radiation. The aperture coupled structure has all of the advantages of the former two structures, and isolates the radiation from the feed network, thereby leaving the main antenna radiation uncontaminated (*Navarro E, Such V, Gimeno B and Cruz J, 1994; Moglie F, Rozzi T and Marcozzi P, 1994*). The microstrip line feed technique is selected to be used in this paper (*Navarro A and Nunez M, 1994*).

Human Models

Most of recent studies are done by using planar, cylindrical and spherical models of the human (*Wu K, Wu C and Litva J, 1994*). That is because these models are the simplest to treat mathematically. Among those several models each working on a different geometrical shape; modeling with a sphere has a special privilege. This comes from its wide range of application that includes electrical engineering, Atmospheric and oceanic science, radar, astronomy, biochemistry and biomedical engineering. Especially in biologic studies it is very difficult to measure the

absorbed electromagnetic (EM) radiation by using planar models since these models fail to take into account the rather complex shape of actual biological object, particularly body curvatures.

Also there are different phantoms available for human simulations. The phantom that is most often used is the SAM phantom. SAM (the Specific Anthropomorphic Mannequin) is a new model based on the 90th percentile dimensions of an adult male head according to an anthropomorphic study of US Army personnel. It compounds two tissues, one shell of 2 mm to represent the skin and one homogenous liquid inside the shell to represent the brain tissue, as shown in Fig. 1. Today, the standard phantom is the generic twin phantom, as illustrated in Fig. 2. The generic twin phantom is based on an anthropomorphic study of 52 European persons (*Pereda J, et al, 1995*).

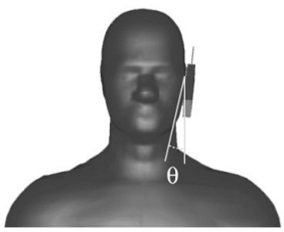

FIG. 1 SAM PHANTOM

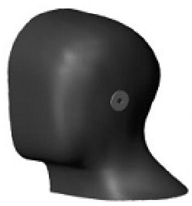

FIG. 2 GENERIC TWIN PHANTOM

In this paper, a human head of the homogenous SAM phantom is used; this means that the brain tissue is approximated with one dielectric constant and one electric loss constant.

For a homogenous phantom head the dielectric properties, for relevant frequency bands, for the tissue simulating the brain are listed in Table 1.

TABLE 1 DIELECTRIC PROPERITIES FOR SYNTHETIC BRAIN TISSUE

Frequency band MHz	Relative permittivity ε_r	Conductivity σ(S/m)
800	46.3 (± 5 %)	0.73 (± 10 %)
900	45.8 (± 5 %)	0.77(± 10 %)
1600	43.9 (± 5 %)	1.06 (± 10 %)
1800	43.5 (± 5 %)	1.15 (± 10 %)
2000	43.2 (± 5 %)	1.26 (± 10 %)
2500	42.5(± 5 %)	1.54 (± 10 %)

The tissue parameters can be derived from the 4-cole-cole Analysis in "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies" by Gabriel, C. Brooks Air Force Technical Report AL/OE-TR-0037-1996. This data is available on Federal Communication Commission's website in the United States (*Prescott D and Shuley, 1994*).

Specific Absorption Rate (*SAR*)

The distribution of the specific absorption rate *SAR* is determined by the distribution of the electric field *E*, the mass of density ρ_m (kg/m³) and the electric conductivity σ (S/m) (*Adel Z. El dein and Alaa El Dein, 2011*).

$$SAR = \frac{\sigma |E|^2}{\rho_m} \tag{3}$$

The *SAR* values are important field quantities, especially in the field of safety issues and numerical dose assessment. Numerous national and international standards and guidelines in the field of human exposure to electromagnetic fields claim for the compliance with so-called basic restrictions.

SAR is a value describing how much power absorbed in biological tissue when the body is exposed to electromagnetic radiation. *SAR* is measured in W/kg and can be expressed in three ways; one way is to compute the value of *SAR* at a point, the second way is to compute an average value of *SAR* in a cell of 1 gram and the third way is to compute an average value of *SAR* in a cell of 10 grams. The interesting areas are the head and the brain tissue. *SAR* is important in the antenna design process since its value is restricted and it is not to be exceeded. In Sweden and the rest of Western Europe the maximum average value is set to 1.6 W/kg over 1 grams by the standardization organization European Committee for Electro technical standardization, CENELEC. In the United States and many other countries the maximum average value is set to 1.6 W/kg over 1gram by another standardization organization called FCC- the Federal Communications Commission (*C. A. Balanis, 2008*).

Table 2 shows the limits, which apply in general for mobile telephones and similar apparatus, are drawn directly from the applicable source document: ANSI/IEEE C95.1 for the US and a few other countries, ICNIRP for Europe and most of the rest of the world. Two limits are used: a lower value for exposure averaged over the whole body, and a higher value which is applicable to local exposure to parts of the body (e.g. head). This partial body SAR is averaged

over a volume of tissue defined as a tissue volume in the shape of a cube. The US requirements differ from the international requirements in their demand for a lower spatial average limit and that this limit is averaged over a smaller volume (1 gram of tissue as opposed to 10 gram). They also require a longer time over which the *SAR* is to be averaged (*S. Drabowitch, A. Papiernik, H. D. Griffiths, and J. Encinas, 2005*).

TABLE 2 LIMITS, WHICH APPLY IN GENERAL FOR MOBILE TELEPHONES AND SIMILAR APPARATUS

	Whole body, *SAR*	**Spatial peak, *SAR***	**Averaging time**	**Averaging mass**
Europe	0.08 W/kg	2 W/kg	6 min	10g
USA	0.08 W/kg	1.6W/kg	30 min	1g

Results and Discussion

This section presents the values of the *SAR* on the human head emitted by three different kinds of antenna that are designed with radiated power of 0.125 watt at 1800 MHz. Also, this section presents the values of the return loss of these three-designed antennas, with and without the presence of the human head model.

The Return Losses

The return loss is the measure of the reflected energy at a given frequency; the less the energy returned, the higher radiated energy.

Figs. 3 and Fig. 4 show the return loss without and with human head model for dipole antenna at 1800 MHz. It is seen that the return losses with human head is higher than that without the human head.

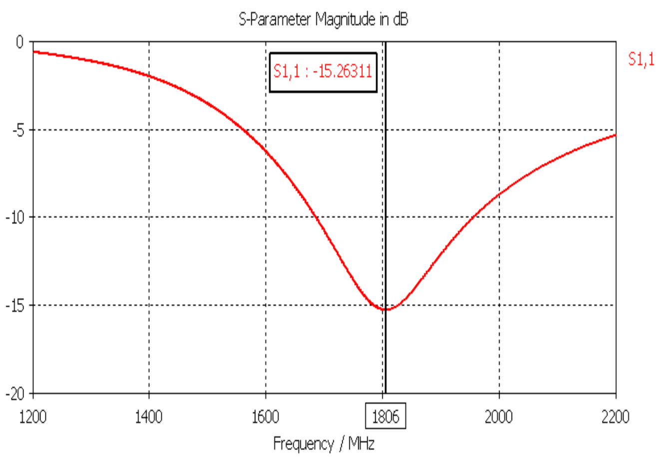

FIG. 3 RETURN LOSS OF DIPOLE ANTENNA WITHOUT HUMAN HEAD (dB) AT 1800 MHz

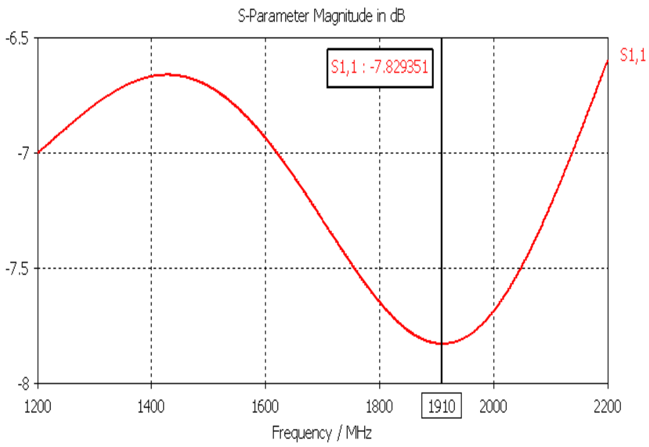

FIG. 4 RETURN LOSS FOR DIPOLE ANTENNA WITH HUMAN HEAD (dB) at 1800 MHz

Also, Figs. 5 and 6 ; and Figs. 7 and 8 show the same results as those of Figs. 3 and 4, except that they are for monopole antenna and patch antenna, respectively.

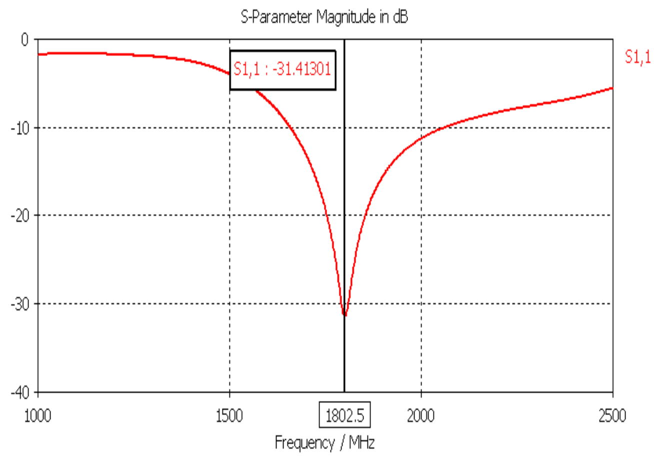

FIG. 5 RETURN LOSS FOR MONOPOLE ANTENNA WITHOUT HUMAN HEAD (dB) at 1800 MHz

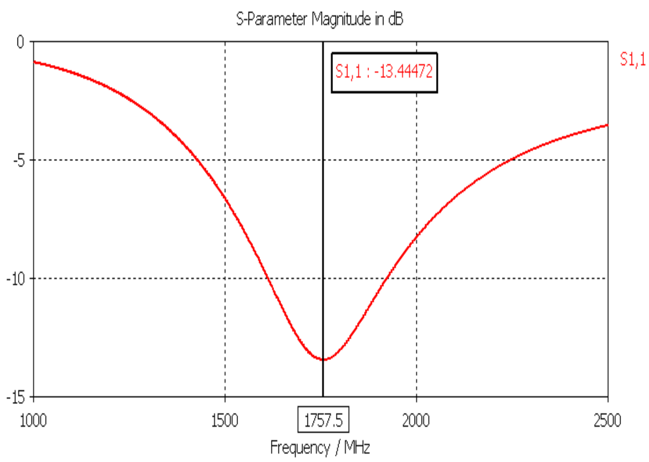

FIG. 6 RETURN LOSS FOR MONOPOLE ANTENNA WITH HUMAN HEAD (dB) at 1800 MHz

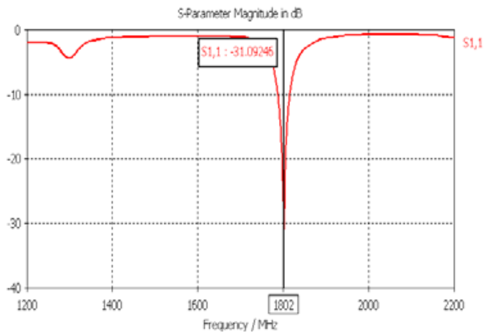

FIG 7. RETURN LOSS FOR PATCH ANTENNA WITHOUT HUMAN HEAD (dB) at 1800 MHz

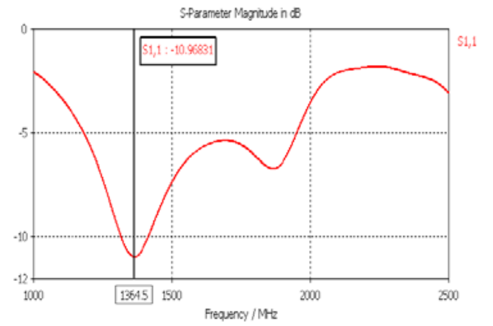

FIG. 8 RETURN LOSS FOR PATCH ANTENNA WITH HUMAN HEAD (dB) at 1800 MHz

The SAR

Fig. 9, Fig. 10 and Fig. 11 shows the Specific Absorption Rate (SAR) distributions on the human head emitted by dipole antenna at 1800 MHz for (point, 1 g and 10 g), respectively, where the radiated power is 0.125 watt.

Also, Figs 12, 13 and 14 and Figs 15, 16 and 17 show the same results as those of Figs. 9, 10 and 11, except that they are for monopole antenna and patch antenna, respectively.

Dipole Antenna

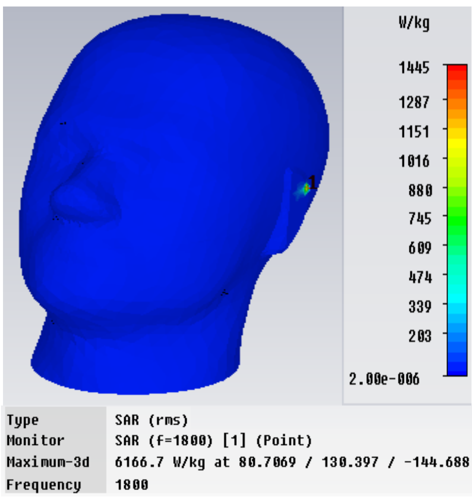

FIG. 9 *SAR* DISTRIBUTION FOR DIPOLE ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (POINT)

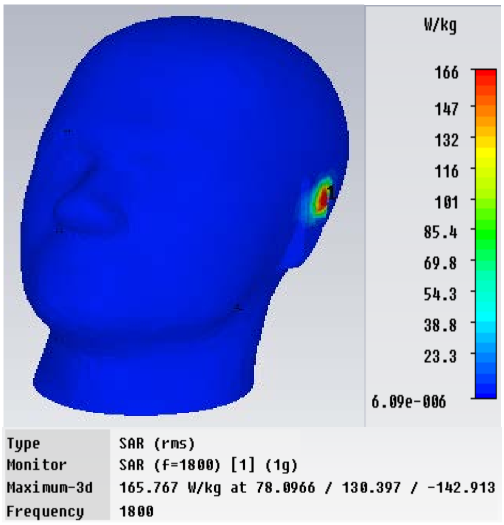

FIG. 10 *SAR* DISTRIBUTION FOR DIPOLE ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (1 GRAM)

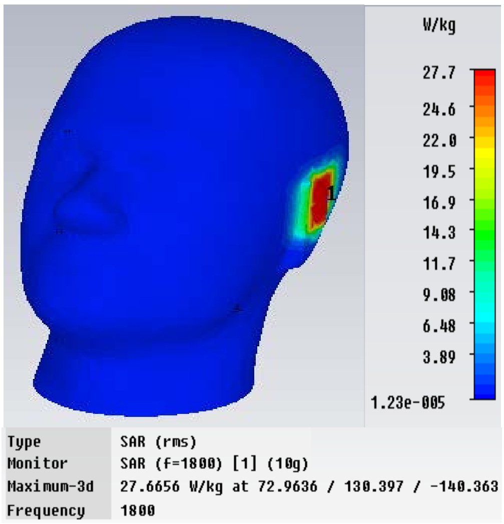

FIG. 11 *SAR* DISTRIBUTION FOR DIPOLE ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (10 GRAMS)

Monopole Antenna

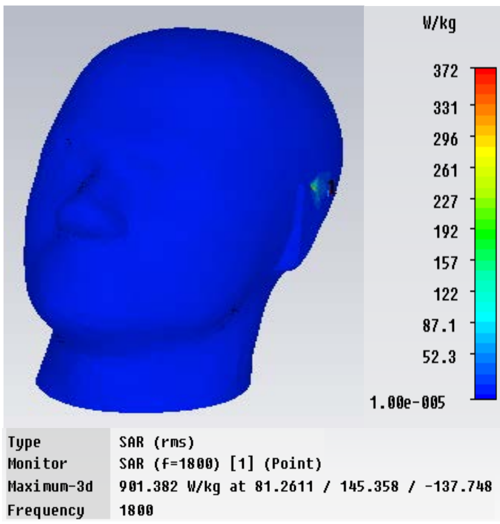

FIG. 12 *SAR* DISTRIBUTION FOR MONOPOLE ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (POINT)

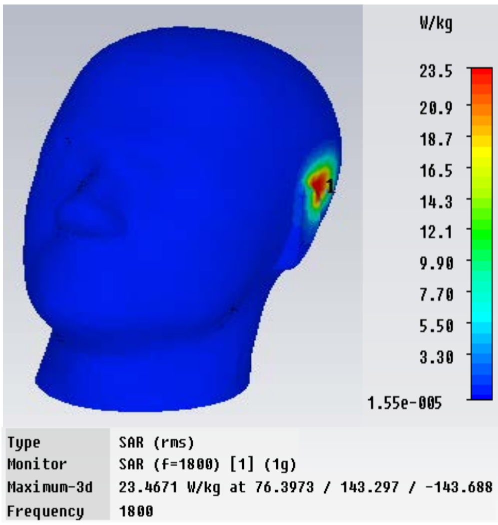

FIG. 13 *SAR* DISTRIBUTION FOR MONOPOLE ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (1 GRAM)

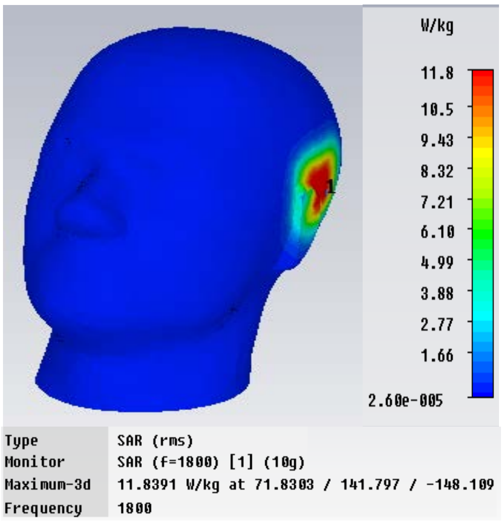

FIG. 14 *SAR* DISTRIBUTION FOR MONOPOLE ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (10 GRAMS)

Patch Antenna

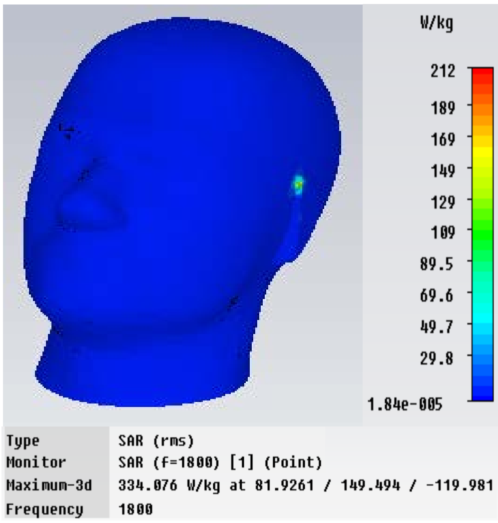

FIG. 15 *SAR* DISTRIBUTION FOR PATCH ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (POINT)

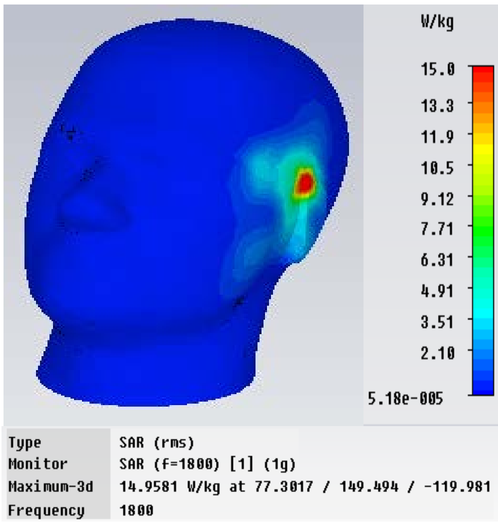

FIG. 16 *SAR* DISTRIBUTION FOR PATCH ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (1 GRAM)

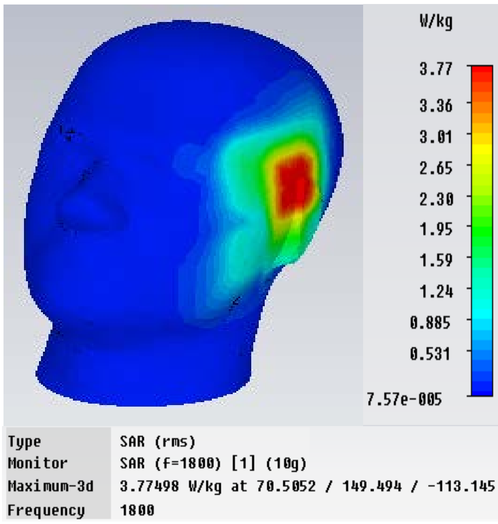

FIG. 17 *SAR* DISTRIBUTION FOR PATCH ANTENNA WITH HUMAN HEAD AT 1800 MHz AT (10 GRAMS)

Table 3 shows a comparison between the return loss without the human head model and with the human head model at 1800 MHz for dipole antenna, monopole antenna and patch antenna. It is seen that for all the investigated types of the antennas, the return loss of the antenna with the presence of the human head is higher than that without the human head. That of course explains the effect of the presence of the human head on the performance of the antenna. The effect of the human head on the mobile terminal antenna designer parameters can not be eliminated, as it is an electromagnetic characteristic.

Table 4 shows a comparison between the *SAR* distribution (point, 1 g and 10 g) at 1800 MHz of the human head that is emitted by dipole antenna, monopole antenna and patch antenna. It is seen that the *SAR* at point is of maximum values compared with

the *SAR* at 1 g and 10 g. and it is noticed that 10 g *SAR*, as it was expected, is less than 1 g *SAR*, that because the sampling weight in this case is 10 times more than that of 1 g. Also, it is seen that at 1800 MHz the *SAR* (point, 1 g and 10 g) for the patch antenna are smaller than those of the monopole antenna, which are smaller than those of the dipole antenna.

TABLE 3 RETURN LOSS WITHOUT AND WITH HUMAN HEAD FOR DIPOLE, MONOPOLE AND PATCH ANTENNA AT 1800MHZ

Antenna	Frequenc , (MHz)	Return loss without human head, (dB)	Return loss with human head, (dB)	Resonant frequency with human head, (MHz)
Dipole	1800	-15.26311	-7.82935	1910
Monopole		-31.41301	-13.44472	1757.5
Patch		-31.09246	-10.96831	1364.5

TABLE 4 *SAR* FOR DIPOLE, MONOPOLE AND PATCH ANTENNA AT 1800MHZ FOR POINT, 1 G AND10 G

Mass, (g)	Frequency, (MHz)	*SAR*, (W/Kg) Dipole antenna	*SAR*, (W/Kg) Monopole antenna	*SAR*, (W/Kg) Patch antenna
point	1800	6166.7	901.382	334.76
1 g	1800	165.767	23.4671	14.9581
10 g	1800	27.6656	11.8391	3.77498

Conclusions

For all the investigated types of the antennas, it is seen that the return loss of the antenna with the presence of the human head is higher than that without the human head. That explains the effect of the presence of the human head on the performance of the antenna.

The *SAR* at a point is of maximum values compared with the *SAR* at 1 g and 10 g. Also, it is noticed that 10 g *SAR*, as it was expected, is less than 1g *SAR* that because the sampling weight in this case is 10 times more than of 1 g. Also, it is seen that the *SARs* (point, 1 g, 10 g) for the patch antenna are smaller than those of the monopole antenna, which are smaller than those of the dipole antenna.

The obtained results show that for the same frequency, the patch antenna induced *SAR* in the human head of smaller values than that induced by dipole and monopole antennas. In addition, the return loss of the patch antenna is affected greatly by the presence of the human model, when it is compared with the return losses of the dipole and monopole antennas.

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Adel Zein El Dein Mohamed Moussa was born in Egypt in 1971. He received the B.Sc. and M.Sc. degrees in electric engineering from the Faculty of Energy Engineering, Aswan, Egypt, in 1995 and 2000, respectively, and the Ph.D. degree in electric engineering from Kazan State Technical University, Kazan, Russia, in 2005. From 1997 to 2002 he worked as a teaching assistant at Faculty of Energy Engineering, Aswan, Egypt. From 2002 to 2005 he was with Kazan Energy Institute, Kazan, Russia and with Kazan State Technical University, Kazan, Russia where he received his Doctor of Engineering Degree. Since 2005, he has been a staff member at the Department of Electrical Engineering, Faculty of Energy Engineering, Aswan University, Aswan, Egypt. His fields of interest include calculation of electric and magnetic fields and their effects, comparison of numerical techniques in electromagnetics, design of microstrip antennas and filters, and the calculation of specific absorption rate (*SAR*) in the human body. (Aswan university, Faculty of Energy Engineering, Electrical Engineering Department, Aswan 81258, Egypt, T + 20973481235, Fax. +20973481234, Mobile +201228008458, e-mail: azeinm2001@hotmail.com).

Mohamed Ahmed Abdel Wahab (SM'98) was born in 1952. He received the B. Sc. and M. Sc. Degree in Electrical Engineering from Ain Shams University, Egypt, in 1975 and 1980 respectively. From 1983 to 1988 he was with Osaka University, Japan where he received his Doctor of Engineering Degree. He was a research fellow at Faculty of Engineering Osaka University from 1988 until 1990. From 1990 to 1991 he was with Mitsubishi Electric Corporation, Japan. From 1991 he is with Faculty of Engineering Minia University. Now, He is a professor and the chairman of the Electrical Engineering Department, Faculty of Engineering, Minia University. His main fields of interest are high voltage phenomena and electromagnetic transients. He is a senior member of the IEEE. (Minia University, Faculty of Engineering, Electrical Engineering Department, Minia, Egypt, T + 20862362083, Fax. +20862346674)

Mohamed Mahmoud Hamada was born in 1951. He received his B. Sc. and M.Sc. from Assiut University, Egypt in 1974 and 1982 respectively and Ph.D. from Manchester University Institute of Science and Technology (UMIST), UK, all in Electrical Engineering. From 1975 to 1983 he worked as a teaching assistant at Minia University, Egypt. From 1983 to 1989 he was with UMIST working with IPSA group and studying for Ph. D. Since 1989, he has been a staff member at the Department of Electrical Engineering, Minia University. He is now working at the same Department as an Associate Professor. His main fields of interest are harmonics in power systems, HVDC, high voltage phenomena, voltage stability. (Minia university, Faculty of Engineering, Electrical Engineering Department, Minia, Egypt, T + 2086236852, Fax. +20862346674, Mobile +20109633963).

Tamer H. Emmary was born in 1982. He received the B. Sc. Degree in Electrical Engineering from Minia University, Egypt, in 2004. In 2006 he joined the west delta electricity company, Damanhour, Egypt as operation engineer. He is now carrying out his research to get M. Sc. Degree from Electrical Eng. Dept. Faculty of Engineering Minia University. His main fields of interest are electromagnetic fields and high voltage phenomena.